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MICROCOMPUTER-BASED REAL-TIME CONTROL OF COMBINED SEWER OVERFLOWS IN THE HAMILTON-WENTWORTH REGION

by

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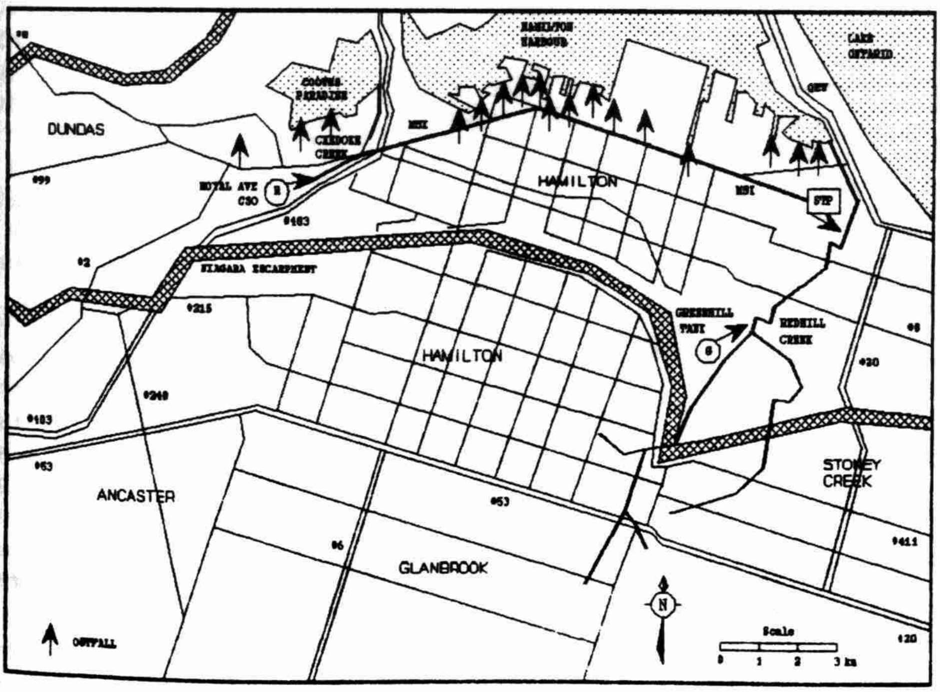
Many Ontarians reside in municipalities which are at least partially serviced by combined sewer systems which handle both stormwater runoff and sanitary wastewater. In these systems, during dry weather, all sanitary sewage is conveyed to local sewage treatment plants (STP) via large sanitary interceptor sewers. These interceptors were generally designed to handle 2 to 5 times dry weather flow. During wet weather, the combined discharge of stormwater runoff and sanitary wastewater often far exceed the capacity of the sanitary interceptors and STP. Diversion structures were typically built into the combined sewer systems to divert flows in excess of this capacity directly to local receiving waters. These discharges are commonly referred to as combined sewer overflows (CSO).

Hamilton's combined sewer system collects sanitary sewage and stormwater runoff from the older portions of the City, bounded by the Harbour headline in the north and the Niagara Escarpment in the south, and from the east end of the City above the Escarpment (see Figure 1). Many area industries also discharge wastewater to the combined sewer system. Separate sanitary and storm sewer systems have been installed in newer suburban areas. Combined sewage from most of the City is conveyed to the Woodward Avenue STP via the 14 km long Main Sanitary Interceptor (MSI) trunk sewer which runs along Burlington Street. During dry weather and small storm events, sanitary and storm flows receive full treatment at Woodward Avenue. Larger rainfall events, specifically high intensity, summer thunderstorms, which generate flows in the combined sewer system in excess of design capacities, may overload the MSI and/or STP, resulting in CSOs to Hamilton Harbour and Cootes Paradise. These diversions are necessary in order to avoid flooding the STP or surcharging the sewer system.

Figure 1: Hamilton-Wentworth Region



Common problems encountered in combined sewer systems include excess infiltration and inflow, sewer surcharging, solids deposition and scour, wet and dry weather CSO, and STP bypasses. Sewer surcharging often results in basement flooding and associated health hazards, public dissatisfaction and costly litigation. Overflows may result in temporary placarding of beaches (warning against swimming and other body-contact recreation) and may also adversely affect fish and wildlife habitats. Long-term deterioration of the environment through eutrophication, sediment contamination and adsorption of toxic chemicals by the biota may result from continued diversions. The Hamilton Harbour Remedial Action Plan (RAP) has identified CSOs as a significant source of ammonia, phosphorus suspended solids, and bacteria within the Harbour, and has recognized the need to reduce these overflows (Rodgers et al., 1988).

Popular remedies for CSO pollution problems include construction of separate storm sewers, storage, treatment, remote monitoring/control, or combinations thereof.

The construction of separate storm and sanitary sewer systems has been one of the most widely used remedies for CSO problems. However the separation of existing combined sewers is often an impractical and costly solution. Waller (1969) estimated that over $4.5 billion might be required to achieve complete separation of combined sewers in Canada. Furthermore, this solution does not adequately address the problem of pollution contributed by separated stormwater.

Storage can be an effective and economical CSO control technique. The concept generally involves the retention of CSOs during storm events, with their release to the sanitary interceptor permitted only after the storm has subsided, at which point the STP can treat the retained volume of wastewater. Types of storage include in-line storage, underground tanks, and above-ground retention tanks. Storage facilities can perform multiple tasks, such as primary treatment, flood protection, and sewer system relief. The Hamilton-Wentworth Regional Engineering Department has recently completed construction of a large CSO retention facility near Greenhill Avenue on the East Mountain (see Figure 1). The tank was designed to limit the frequency of CSOs into Redhill Creek at this site to once per year on average. Stored wastewater is subsequently released into the Redhill Creek Sanitary Interceptor Sewer and conveyed to the Woodward Avenue STP for treatment. Operation began in the Fall of 1987. The Region has retained a consultant to evaluate the actual performance of the facility.

Common treatment methods include physical/chemical treatment and disinfection using ultra-violet light or chlorine. These processes can be implemented at the existing STP as is usually the case, or at additional smaller facilities located at CSO outfalls.

Remote monitoring and control techniques are aimed at improving the operator's knowledge of the combined sewer system, and how it performs during a storm event, thereby allowing more effective control of CSO regulators and/or storage/treatment facilities. The Hamilton combined sewer system contains about 165 diversion structures, with 26 outfalls to local receiving waters (see Figure 1). A number of these structures employ motorized gates which can be opened or closed to regulate flow to the sanitary interceptor. These gates are either activated automatically by water level sensors, or remotely by operators at the Woodward Avenue STP. In the absence or more detailed information, the operator's decision is based upon general predictions, wet-well depths and flow readings

at a various sites throughout the City (Henry, 1984). However, the dynamic spatial and temporal properties of rainfall events, especially summer thunderstorms, can generate runoff responses where some sections of the sewer system are overloaded while others, which may be in close proximity, are flowing at well below capacity. Without adequate knowledge of the direction, speed, and extent of a thunderstorm, gates may be closed well before the sanitary interceptor's capacity is fully utilized, and may remain closed long after flow subsides. While such a procedure results in maximum safety for the STP and a lower probability of basement flooding, CSO frequencies and volumes are likely greater than necessary. More precise control of automatic CSO regulators should provide the capability to optimize use of the sanitary interceptor, thereby reducing CSO, while still maintaining the desired protection against STP overload and basement flooding.

The advent of low-cost microcomputers has introduced the possibility of economically controlling CSO diversion structures and/or storage in real-time to minimize CSO in wet and dry weather. To date, this approach has not been sufficiently tested in Ontario. In 1987 the Region made application to the Ontario Ministry of the Environment (MOE) for funding of a demonstration project to evaluate microcomputer-based real-time control (RTC) of combined sewer overflows. The site chosen for the project was the Royal Avenue diversion structure in West Hamilton. The study was approved by Regional Council and the MOE in 1987 and work began in 1988. This paper outlines the objectives and scope of the demonstration project and the proposed approach to the problem.

STUDY AREA

The City of Hamilton is one of Canada's major industrialized urban centres. The City includes two of North America's largest steel makers, Stelco and Dofasco, and supports a population of well over 300,000. The area's topography is characterized by a number of major natural features which influence land use and drainage patterns, the most influential of these being the Niagara Escarpment. The Escarpment divides the Region into upper and lower sectors, which have an average difference in elevation of about 108 m. The terrain of both the upper and lower portions of the area are nearly flat. The Escarpment is cut by a number of deep valleys, the most significant of these being the Dundas Valley. The area generally drains eastward or northeastward to the receiving waters of Hamilton Harbour and Cootes Paradise (see Figure 1).

Prevailing winds are generally from the southwest. On an annual basis, southwest winds occur about 37 percent of the time and dominate the period the period from July to January. Wind speeds are generally between 10 to 20 km/hr. The most significant sources of atmospheric pollution are the heavily industrialized area on the south shore of the Harbour, and the Central Business District (Shivalingaiah and James, 1986). Northeast and east winds play an important role in distributing airborne pollutants over the City. Hamilton is also extremely susceptible to atmospheric inversions, caused by differential heating of the lake and land surfaces (Rouse and McCutcheon, 1972). These inversions may result in increased surface pollutant buildup and washoff.

The significance of storm speed and direction on the response of Hamilton's storm and combined sewer system to thunderstorms has been studied in great detail. Robinson and James (1984) used the Stormwater Management Model (SWMM) developed by the U.S. EPA (Huber et al., 1981) and the RAINPAC package developed by Scheckenberger (1983) to determine the sensitivity of the response of a portion of Hamilton's combined sewer system to storm speed and direction. SWMM is a deterministic simulation package which generates surface runoff and pollutant washoff from user supplied rainfall hyetographs, based on land use, topography, and antecedent conditions. Hydrographs and pollutographs can be routed through a network of manholes, lift stations, overflow structures, storage facilities, and various shapes of conduits, as defined by the user. SWMM is one of the best known and most widely used urban runoff quantity and quality models. RAINPAC is a set of dynamic spatially variable rainfall models which can be used to prepare rainfall hyetographs for water quantity and/or quality models such as SWMM, accounting for:

- Storm cell speed and direction;
- Storm cell direction;
- Growth and decay of peak rainfall intensity;
- Growth and decay of storm's areal coverage;
- Multiple storm cells.

Figures 2 and 3 illustrate the effects of varying the direction and speed of a hypothetical thunderstorm event on the response of the Chedoke Creek Drainage Basin in West Hamilton. The Royal Avenue CSO Diversion Structure is located within this catchment. A storm coming from the southwest, and thus following the general direction of the drainage network, will result in significantly higher peak flows than a similar storm coming from other directions (see Figure 2). In addition, a critical storm speed exists for the drainage basin, where storm travel time over the basin is comparable to its characteristic runoff response time. Figure 3 indicates that storms travelling at between 10 and 20 km/hr will generate the highest peak flows. A given storm will thus yield the highest peak flows when travelling at 10-20 km/hr, in the direction of the drainage network, i.e. from the southwest. When such a storm occurs, peak flows from the sub-drainage basins in the catchment arrive at the downstream end of the system at the same time, yielding higher peak total flows. This should not be thought of as an unusual occurrence. In fact, summer thunderstorms in Hamilton generally come from the southwest (Scheckenberger, 1983; Nimmrichter, 1986), and storm speeds of 10-20 km/hr are quite common.

The automatic diversion structure located at the eastern end of Royal Avenue, near the intersection with Stroud Road, has been chosen to demonstrate the feasibility of microcomputer control of CSO diversion structures. The Royal Avenue Diversion Structure drains an area of approximately 600 ha, divided by the Niagara Escarpment (see Figure 4). The area below the Escarpment is serviced predominantly by combined sewers, while the drainage network above the Escarpment is entirely separated. Combined sewers service approximately 35 percent of the basin. Separated stormwater runoff and combined sewage are conveyed to the CSO structure via the same 9'6" x 7'9" trunk sewer. During smaller storms, these flows are separated by a 2' high wall which divides the sewer. During larger events, flow depths may exceed 2', and the two flow streams will be mixed. The CSO regulator at Royal Avenue utilizes a motorized gate to control the flow of combined sewage from the trunk sewer to the interceptor. Excess flows are diverted, untreated, to the Chedoke Creek Channel at the trunk sewer's outlet.

Figure 2: Storm Direction Comparison

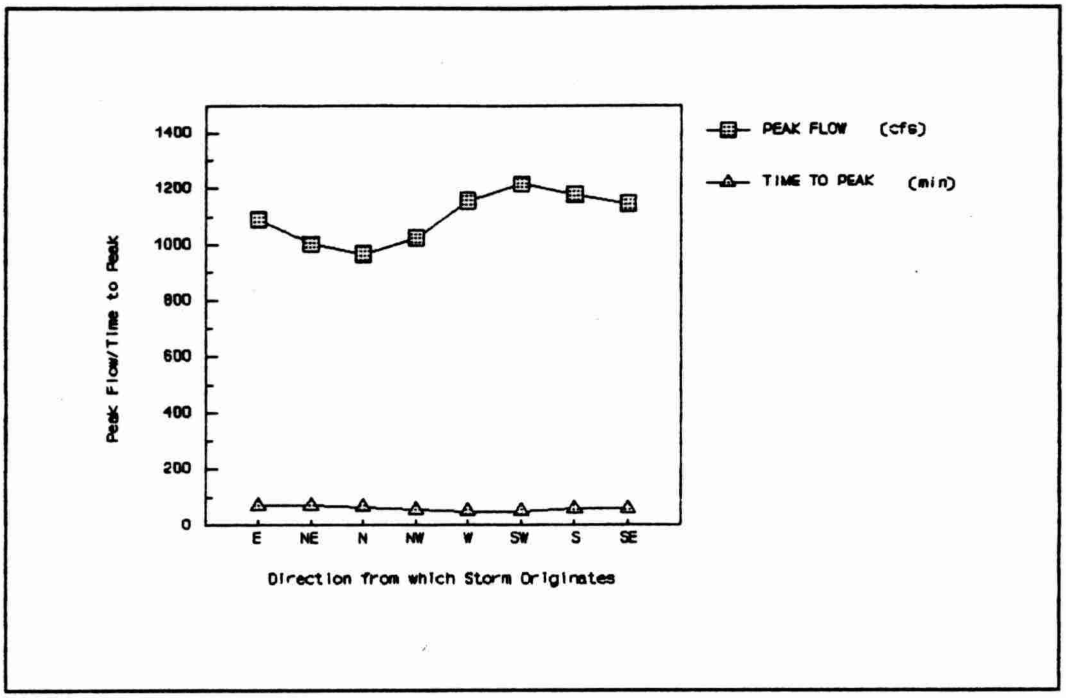


Figure 3: Storm Speed Comparison

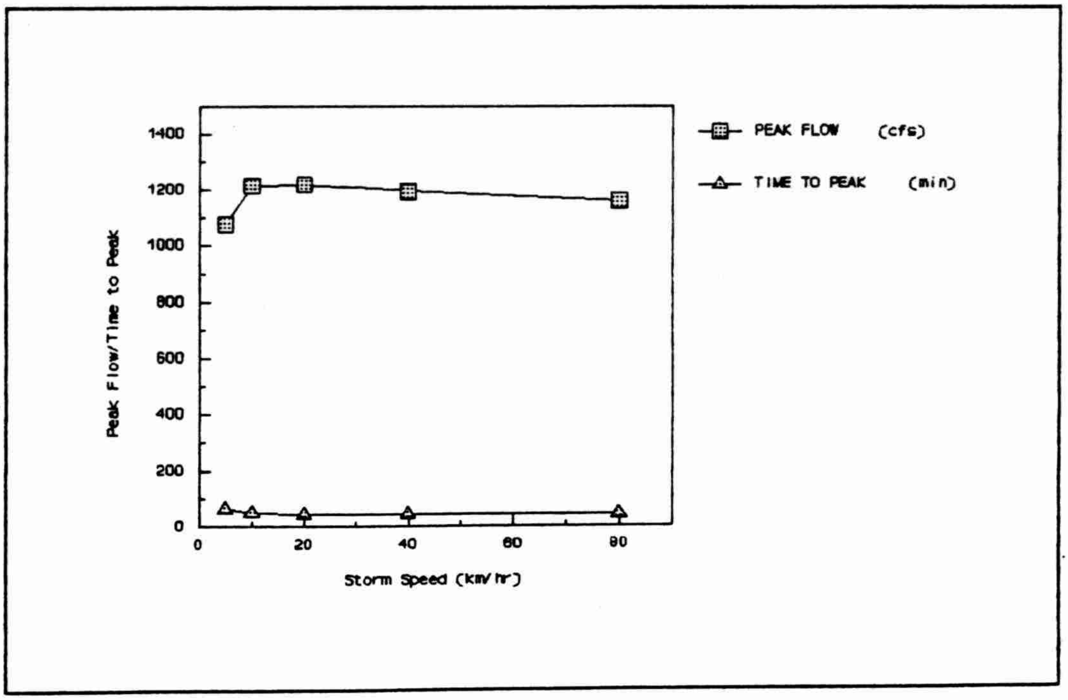
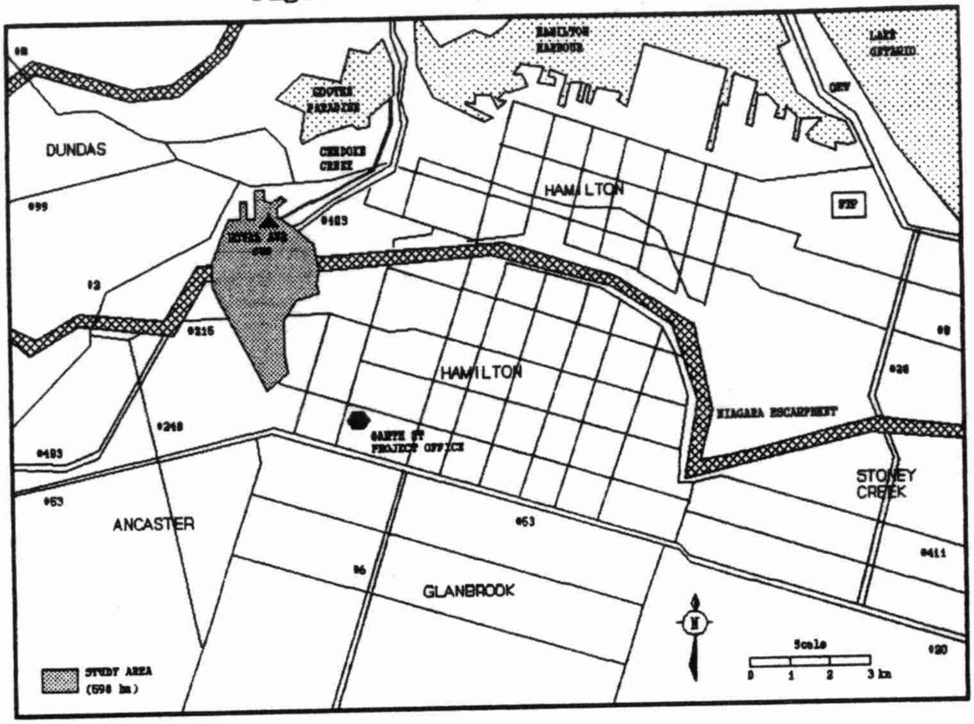


Figure 4: Study Area Location



STUDY OBJECTIVES AND SCOPE

The primary objectives of this demonstration study are:

1) To design a microcomputer-based RTC system for managing CSO diversion structures;

2) To install, operate and evaluate the RTC system at the Royal Avenue CSO diversion structure for the purpose of demonstrating the practical application of this particular technology;

3) To develop a theoretical operating strategy for a larger portion of Hamilton's trunk sanitary interceptor, based on the technology developed for the pilot site;

4) To produce a document which will facilitate transferral of this technology, with emphasis on medium-sized municipalities in Ontario.

While the evaluation of the RTC system at Royal Avenue will be based mainly on its ability to reduce CSO to local receiving waters, the primary purpose of the project is to test the feasibility of this new technology, not to completely solve Hamiliton's CSO pollution problem.

APPROACH

As currently envisioned, the RTC system at the Royal Avenue CSO Diversion Structure will include the following hardware and software components:

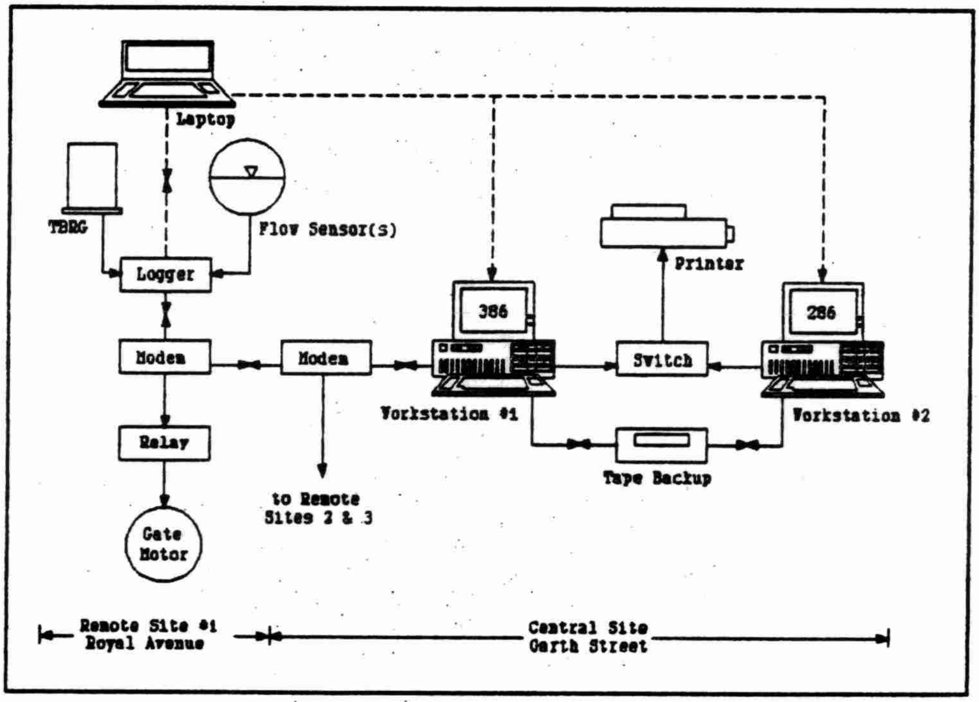
1) Real-time monitoring network and telemetry system;

2) Microcomputer controller and interface with monitoring network and gate;

3) RTC operational model, including real-time water quantity and/or quality forecasting and database management.

Figure 5 presents a schematic of the hardware configuration proposed for the RTC system. The central control site will be located at the Garth Street Reservoir project office (see Figure 4).

Figure 5: RTC System Hardware



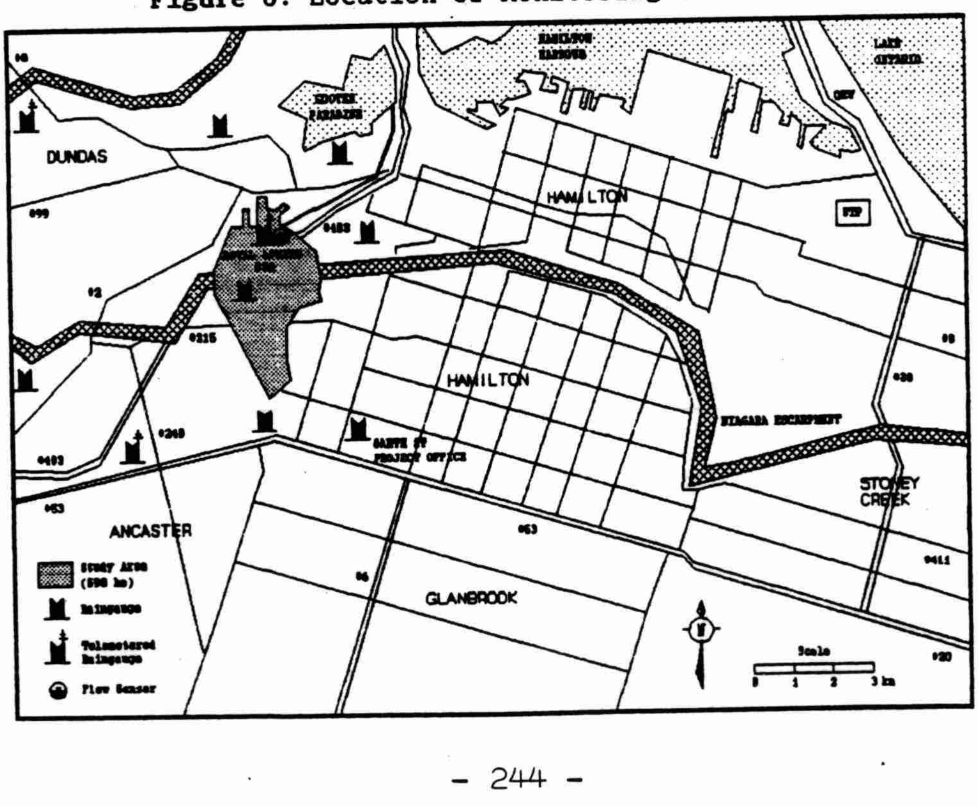
Hydrometeorologic Monitoring Network

A monitoring network comprising at least 10 raingauges, 2 automatic water level/flow sensors (both located at Royal Avenue) and 1 automatic water quality sampler is to be installed and operated. At least 3 of the raingauges will be connected to the central control site by modem and telephone line to permit real-time collection of rainfall data. The water level/flow sensors will be similarly connected.

Appropriate knowledge of storm dynamics is essential for hydrologic modeling and forecasting. For successful control of CSOs, this information must be made available in real-time, at very frequent intervals (say every 1-5 minutes). The raingauge network must be dense enough to accurately describe the spatial and temporal variabilities of storm events. The raingauges themselves must provide sufficient resolution of rainfall over a wide range of intensities. They should also be solidly constructed and suitable for unattended outdoor use. The signal produced by the raingauges must be compatible with electronic data loggers. After reviewing available rainfall sensors, the project team purchased 10 tipping bucket raingauges (TBRG), each with a 0.2 mm rainfall resolution, accurate to 1 percent of the bucket volume. These gauges measure rainfall rates between 0 and 380 mm/hr. The complete network of 10 raingauges cost approximately $13,000.

The raingauges were installed in late April. In most cases the gauges are located on the roofs of municipal facilities, i.e. sewage pumping stations and reservoirs. An enclosure was constructed at the Royal Avenue site, where the raingauge sits atop the regulator chamber, just above ground level. The locations of the 10 rainfall monitoring stations are shown in Figure 6. The 8 outer raingauges were situated to create a ring around the catchment, providing information relating to storm speed, direction, intensity, and coverage. The 3 westernmost stations were located further from the catchment to obtain advance information pertaining to storms coming from the southwest, the prevailing storm direction in the area. The 2 gauges located within the catchment provide the detailed information required to forecast flows arriving at the Royal Avenue CSO Regulator, i.e. the amount of the rainfall falling on the catchment. The orientation of the 10 gauges should quicken the process of determining storm speed and direction and facilitate real-time flow forecasting.

Figure 6: Location of Monitoring Stations



As storm speed and direction are often closely correlated to wind speed and direction, anemometers may also be useful to the RTC system in determining storm dynamics. The project team will investigate the benefits of adding anemometers to some or all of the monitoring stations.

Electronic data loggers are necessary to transfer the signals from these sensors into numerical quantities and temporarily store the results. Permanent storage of this data is best left to more powerful microcomputers. The data loggers must thus provide a convenient means of transferring the data to other microcomputers. Some stations will be connected to the central control site via modem and telephone line. It is anticipated that all sites will be visited weekly or bi-weekly to retrieve data with a portable microcomputer. The data loggers should provide enough storage to handle the data collected during these unattended periods. In addition, to protect against loss of data during power failures, the units should operate on both AC and DC current, and require very little power. The batteries should be rechargeable and have long lives.

Rainfall sensors transmit pulse count (digital) signals. Anemometers, which measure wind speed and direction, and sensors which measure fluid levels/flows and pollutant concentrations, or detect valve positions, transmit an analog signal. As some of the monitoring stations may incorporate a number of these sensors, the data loggers should provide several digital and analog input channels. An automatic water quality sampler will be installed at Royal Avenue to characterize the pollutional strength of the CSO at this site. The data logger should provide a means of triggering the automatic sampler, when say, a critical water level is reached.

Rainfall intensities will generally be averaged over a one-minute timestep. For water levels/flows and/or pollutant concentrations, sampling intervals of five minutes or more may prove adequate. Sampling frequencies for the digital and analog input channels should therefore be software selectable. The data loggers should have built-in real-time clock/calendars to ensure proper time synchronization of the various monitoring stations.

After reviewing a number of different data collection units, the project team purchased 10 portable electronic dataloggers, each with a 10 Volt rechargeable battery pack, 120 Volt AC adaptor/charger, 32 kBytes of solid-state memory, a low-drift real-time clock/calendar, individually software selectable digital and analog input channels (8 of each), a voltage regulated output control, and a 4800 baud modem connection. RS232 serial communications with other microcomputers (including IBM-PC compatibles) is supported through a direct connection with the aid of a serial communications interface, or via modems on dedicated or dial-up telephone lines. IBM-PC-based software is provided to facilitate data transfer and processing and can also be used to remotely configure or reprogram the dataloggers. Processing of recorded information to generate graphs and data tables can be performed on-site for immediate viewing, if desired.

The operational model which will drive the RTC system requires frequent transmission of information to a central site from points within the drainage basin, including wind speed and direction, rainfall intensity, water level/flow, pollutant concentration, and regulator status. Thus, a means of communicating this information to the central site is necessary. The data loggers purchased by the project team can be accessed via modem over dial-up or dedicated telephone lines by a microcomputer and modem located at the Garth Street Reservoir project

office. Initially, 3 real-time monitoring stations will be set up within the study area. Modems were purchased with the dataloggers for these stations. Data will be retrieved from these sites via dialed public telephone lines at 1200 baud. Should the occasional unavailability or the quality of public telephone lines limit the performance of the RTC system, leased telephone lines will be utilized.

The entire system, comprising ten dataloggers, each with batteries and chargers, three 1200 baud modems, one RS232 serial communications interface, and the IBM-PC-based software cost under $17,000.

In any telemetry and remote control system, the software which handles data transmission is very important. The software handles communications protocol, checks the data for errors upon receipt, and ensures data transmissions are properly synchronized such that data loss due to signal collisions is minimized, or otherwise accounted for. Communications software provided with the dataloggers purchased by the project team handles these tasks. Software has also been developed by the project team to suit more specific study requirements. In addition, with the aid of either software package, the central microcomputer can reconfigure each of the dataloggers at any time, providing new operating instructions (eg. changing sampling intervals, communications protocol, etc.). New operating characteristics can be verified by the central microcomputer. When the central computer has terminated communications, the datalogger will disable its communication operation and return to its datalogging function. Real-time communications software is currently being developed by the project team.

A portable microcomputer provides the most efficient means of retrieving data from the other seven monitoring stations, and can also be used to program the dataloggers in the field (eg. select timestep, communications protocols, etc.). After reviewing available hardware, the project team purchased an IBM-PC compatible laptop microcomputer, outfitted with 2 floppy disk drives, a serial communications port, a rechargeable battery and a car cigarette lighter power adaptor, at a cost of about $2,000. The car cigarette-lighter adaptor was purchased to recharge of the laptop's batteries while field staff travel from site to site to retrieve data from the loggers. Data which has been stored in the datalogger is downloaded to the laptop's serial port via the RS232 serial communications interface using the aforementionned software. By transmitting simple instructions through this communications link, the laptop can modify the operating characteristics of the dataloggers, and verify the new configuration.

The laptop also allows field staff to perform some simple data processing and display the data graphically while they are at the field sites. This allows prompt identification of any instrument difficulties. Minor problems can then be addressed immediately and the laptop can be used to verify their resolution before departing the site. Instruments in need of more major repairs can be taken back to the project office and repaired.

Upon returning from the field sites, the data is transferred to a desktop PC at the central site for further processing and archiving. Data processing software has been developed by the project team to separate the rainfall records into distinct storm events. The applicability of smaller, less expensive, hand-held microcomputers to field data retrieval may be investigated by the project team.

Microcomputer Hardware

A powerful desktop microcomputer is required to serve as the central processor for the RTC demonstration system at the Royal Avenue CSO Diversion Structure (Workstation #1). This machine, hereinafter referred to as the Central Microcomputer Controller (CMC), will be required to perform the following tasks every 1 to 5 minutes:

1) Communicate with and retrieve data from a real-time monitoring network comprising at least 3 raingauges and 2 water level/flow sensors via modem and telephone line;

2) Using this data, predict important wind and/or rainfall characteristics within the study area, and resulting water levels/flows at the overflow structure, ahead of time;

3) Based on the predicted information, determine the optimum gate control strategy, and if necessary, send a signal to the overflow structure via modem and telephone lines to move the motorized gate to the desired position (an electrical relay will be required to activate the motor);

4) Archive information pertaining to rainfall intensity, water level/flow, and gate position in a data base management system;

5) Present important information clearly, with the aid of colour graphics, to allow intervention by a supervisor, where necessary.

As the complexities of the RTC system are unknown before its development and testing are completed, hardware was selected so as not to restrict the use of more advanced and computationally intensive techniques should research indicate they are necessary to achieve the desired results. The CMC requires high computational speed, large disk storage, high resolution colour graphics, and should be IBM-PC compatible. After reviewing available hardware, the project team purchased a 25 MHz, 80386-based desktop PC, outfitted with a high speed math co-processor, a 110 MB RAM hard disk drive, a high resolution VGA colour monitor and controller, and a 1200 baud modem. The modem will allow the CMC to communicate with at least 3 dataloggers located within the study area. The cost of fully equipping Workstation #1 was about $17,000.

A second microcomputer is required to carry out every day tasks related to the development of the RTC system (Workstation #2). Tasks will include:

1) Long-term continuous simulations to generate continuous water quantity and quality records;

2) Storage and management of rainfall, water level/flow, and/or pollutant concentration data collected from at least 10 stations;

3) Statistical analysis of long-term records and continuous simulations to develop a real-time rainfall-runoff forecasting model;

4) Continuous simulations to evaluate alternative control strategies;

5) Development and testing of specialized software related to the above tasks.

A fast processor and large hard disk drive are necessary to undertake the long-term simulations and manage the related input/output, which can reach up to 5 MBytes per file. After reviewing available hardware, the project team purchased a 6-10 MHz, 80286-based desktop PC, and outfitted it with a high speed math co-processor and 40 MByte hard disk drive. The cost of fully equipping Workstation #2 was about $5,000. Prior to being dedicated as the CMC, Workstation #1 can be used to perform similar tasks as Workstation #2.

Workstation #2 may also be linked to the CMC to provide backup in case of CMC hardware malfunctions. This may require development of a second, less complex RTC operational model, which could run on the 80286-based PC. Power outages and surges, which would affect both Workstation #1 and #2 may have to be protected against by an uninterruptable power supply (UPS). A UPS system will be purchased in the future if deemed necessary.

Should the demonstration project indicate that the RTC system does not fully utilize the computing power provided by the 80386-based machine, less powerful, less costly alternatives (for the CMC) should be investigated. The 80286-based PC provides an opportunity to do so. After successfully installing and testing the RTC system on Workstation #1, the project team will attempt to install the same system on Workstation #2 and evaluate its performance (as the CMC).

Real-Time Control System Software

A centralized database management system (DBMS) will be developed by the project team to process, store and retrieve data. This system will be required to handle two different tasks:

1) Management of a permanent database, containing all collected rainfall and water quantity and quality data;

2) Interim management of telemetered data to provide an interface with the RTC operational model and the permanent DBMS.

Software will be developed to allow the CMC to retrieve data from the telemetered sites in real-time, every 1 to 5 minutes. This data will provide input to the rainfall-runoff forecast model. Data from the remote raingauge stations is collected in the field using the laptop microcomputer and subsequently transferred to the permanent DBMS, which resides on Workstation #2.

A suite of water quantity/quality models is being assembled which will allow the following tasks to be completed:

1) Estimation of current (i.e. no RTC) CSO frequency and volume to provide a basis for evaluation of theoretical RTC system performance;

2) Generation of continuous rainfall-runoff timeseries to provide a basis for development of a real-time rainfall-runoff forecast model;

3) Development of a RTC simulation model which incorporates the forecast model and allows the theoretical evaluation of the performance of any number of proposed operational strategies over a lengthy continuous period.

The models will be capable of simulating storm dynamics, rainfall-runoff processes, flow routing, in-line and off-line storage and the hydraulic operation of diversion structures, in continuous mode. The RUNOFF and TRANSPORT modules of PCSWMM3 (James and Robinson, 1985) will likely form the basis for the model package, but additional software development may be required for specialized processes. RAINPAC (Scheckenberger, 1983) will be used to analyze storm directions and speeds and aid in calibrating the water quantity/quality models. Flow forecasts in the trunk sewer at Royal Avenue will be generated from previous measured rainfall intensities and predicted and/or measured flowrates. Once actual flow readings are available, they will be substituted for corresponding flow predictions or used to recalculate forecast model parameters. Repeated every timestep, this will provide the model with a self-correcting feature to ensure that runoff forecast errors do not accumulate. The PCSWMM3 EXTRAN module will be used to simulate the effects of the proposed RTC system on the hydraulic grade lines in the combined sewer system during the larger storms.

Field Demonstration and Evaluation

After identifying the optimum theoretical control strategy the RTC system will be installed at the Royal Avenue CSO Diversion Structure for the purpose of verifying its performance in the field. Before testing the entire system, the operation of individual hardware and software components will be verified under controlled conditions. The reliability of the system will then be evaluated during actual storm events. Data will be collected during storm events to verfify the results obtained by simulation.

Based on the performance of the proposed RTC system, a theoretical operating strategy for a larger portion of Hamilton's trunk sanitary interceptor will be developed. This task will be conducted exclusively as a modeling exercise.

Finally, a document will be prepared, aimed at facilitating transfer of this technology to other municipalities. As most of the Ontario communities which are still serviced by combined sewer systems have populations in excess of 50,000, emphasis will be placed on medium-sized municipalities.

ACKNOWLEDGEMENTS

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